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# Influence of vibration coupling between bandsaw frame and feed-carriage system on sawdust spillage and surface quality of workpiece during sawing

**Reynolds Okai**

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**Abstract** Productivity, surface quality, and recovery are three parameters that compete for attention during lumber production. The well known phenomenon of improved surface quality with decreasing workpiece feed rate has been reported by several researchers. This paper reports on experimental results from the relationship between workpiece feed rate or bite per tooth and the surface roughness of Japanese Sugi (*Cryptomeria japonica*) using a bandsaw machine whose feed-carriage is coupled to the bandsaw frame. The volume of sawdust produced during sawing was determined using an electronic balance. Equation was developed to determine the kerf-losses. It was observed that as the workpiece feed rate increased, or as the bite per tooth increased, the saw blade vibration decreased and the volume of sawdust also decreased contrary to expected results. Furthermore it was observed that with increasing workpiece feed rate the surface roughness decreased contrary to expected results. On the other hand, when the carriage feed rate increased the saw blade deviation also increased as expected. The research findings clearly suggest that when there is vibration coupling between the feed-carriage and the entire bandsaw frame, the amplitude of the saw blade vibration and the surface roughness decrease as the bite per tooth increases. Thus the bandsaw machine whose frame is coupled to the feed-carriage is a promising technique for increasing lumber recovery and improving upon surface quality.

R. Okai (✉)
Department of Design and Technology Education,
University of Education, Winneba Kumasi Campus,
P.O. 1277, Kumasi, Ghana
e-mail: reynoldsokai@yahoo.co.uk

**Einfluss der Schwingungskopplung zwischen der Bandsäge und dem Vorschubwagen auf den Schnittverlust und die Oberflächenqualität des Schnittholzes**

**Zusammenfassung** Die drei Parameter Produktivität, Oberflächenqualität und Ausbeute sind bei der Schnittholzproduktion zu beachten. Es ist bekannt, dass sich die Oberflächenqualität verbessert, wenn die Vorschubgeschwindigkeit verringert wird. Dies wurde bereits von einigen Forschern berichtet. In dieser Studie wird der Zusammenhang zwischen der Vorschubgeschwindigkeit bzw. dem Vorschub pro Zahn und der Oberflächenrauhigkeit von Sugi (*Cryptomeria japonica*) beim Einschnitt mit einer Bandsäge, deren Vorschubwagen mit dem Sägerahmen verbunden ist, untersucht. Die beim Einschnitt anfallende Sägemehlmenge wurde mit einer elektronischen Waage bestimmt. Zur Bestimmung der Schnittverluste wurde eine Gleichung entwickelt. Es hat sich gezeigt, dass mit zunehmender Vorschubgeschwindigkeit bzw. zunehmendem Vorschub pro Zahn die Vibration des Sägeblatts abnahm und die Sägemehlmenge damit entgegen den Erwartungen ebenfalls abnahm. Des Weiteren nahm auch die Oberflächenrauhigkeit mit zunehmender Vorschubgeschwindigkeit ab. Andererseits ist die Abweichung des Sägeblatts mit zunehmender Vorschubgeschwindigkeit angestiegen. Die Untersuchungen weisen deutlich daraufhin, dass bei vorhandener Schwingungskopplung zwischen Vorschubwagen und dem ganzen Sägerahmen die Schwingungsamplitude des Sägeblatts und die Oberflächenrauhigkeit mit zunehmendem Vorschub pro Zahn abnehmen. Somit erweist sich eine Bandsäge, deren Rahmen mit dem Vorschubwagen gekoppelt ist, als eine viel versprechende Technik zur Steigerung der Schnittholzausbeute und für eine verbesserte Oberflächenqualität.

## 1 Introduction

Saw blade vibration is a highly undesirable phenomenon in the wood industry that has to be investigated thoroughly for efficient wood processing. Excessive blade vibration would lead to huge amount of sawdust spillage or huge saw-kerf losses resulting in low lumber yield. Besides, excessive vibration could contribute to the formation of washboards an undesirable phenomenon that occurs on surfaces of sawn lumber (Okai et al. 1995, 1996, 1997, 2006, Luo et al. 2001, 2003, Hutton and Dalziel 2003, Orlowski and Wasielewski 2001, 2003). If one is able to quantify the volume or weight of sawdust produced during sawing, then one can determine the saw-kerf loss knowing the kerf width of the saw blade.

It is universally acknowledged that excessive feed speed would lead to increased saw blade vibration and consequently the kerf losses would increase, and surface roughness of the sawn lumber would also increase. Besides, there is also a substantial increase in lumber thickness variation when saw blade vibration increases Okai et al. 2006. Productivity can be increased if the workpiece is sawn at high feed speed. However, any attempt to increase productivity could lead to a reduction in product quality. In order to reduce the volume of sawdust spillage during sawing, thin-kerf saw blades have been introduced. A major disadvantage of thin-kerf saw blades is that they are less stable than thicker saws. However if thin-kerf saw blades are properly tensioned they can withstand the rigorous sawing conditions.

Researchers continue to conduct investigations to minimize saw blade vibration during cutting. One fundamental issue that needs to be addressed during cutting is the vibration coupling between the bandsaw frame and the feed carriage. Traditionally, the feed-carriage is decoupled from the bandsaw frame and consequently vibration of the feed-carriage is transmitted to only the saw blade during cutting. However, some bandsaw systems in recent time have the entire frame coupled to the feed-carriage and therefore vibration would be transmitted to both the saw blade and the bandsaw frame. So far, no work has been reported on vibration coupling between the feed-carriage and the bandsaw frame and this has been the motivation for the present study. The kerf-loss and surface roughness of lumber produced from stellite-tipped and tip-inserted saws under vibration coupling condition between the feed-carriage and the bandsaw frame at variable wheel rotation speed, feed speed or bite per tooth is presented in this report.

## 2 Materials and methods

The workpiece used for the study was Japanese Sugi (*Cryptomeria japonica*) with a moisture content greater than 100%, specific gravity of 0.43; thickness of 30 mm; and length of 400 mm. Cutting tests were conducted using a 700 mm diameter band saw with axle to axle wheel separation of 1250 mm. The length, width, and thickness of the saw blade were 4700 mm, 50 mm and 1.06 mm, respectively. Two saw blades were used namely, stellite-tipped saw and tip-inserted saw. The number of teeth, pitch, and depth of gullet of the saw blades were 188, 25 mm, and 9 mm, respectively. The rake angle, clearance angle and sharpness angles of the saw blades were: 27°, 18°, and 45°, respectively. The saw kerf width was 2.03 mm for the stellite-tipped saw and 2.15 mm for the tip-inserted saw.

### 2.1 Sawing tests

The wheel rotation speed was varied from 250 rpm to 850 rpm in steps of 200 rpm and wood samples of Sugi sawn at feed rate of 3 m/min to 15 m/min in steps of 3 m/min, and parallel to the grain at a nominal thickness of 20 mm. Each cutting test was repeated 10 times. Two displacement sensors were positioned at 35 mm below the workpiece to measure the saw blade vibration. Signals from the sensors were saved to computer disk memory using an analog-digital converter. The signals were digitized at a sampling rate of 2000 Hz. Component of cutting forces in the feed and vertical direction were also measured by transferring the signals from two load cells to computer disk memory using the analog-digital converter. A photo of the experimental bandsaw is shown in Fig. 1.

### 2.2 Measurement of sawdust volume, board width and saw kerf-loss

An electronic balance was used to determine the amount of sawdust produced during sawing. The dimensions and weight of each board to be sawn was determined prior to

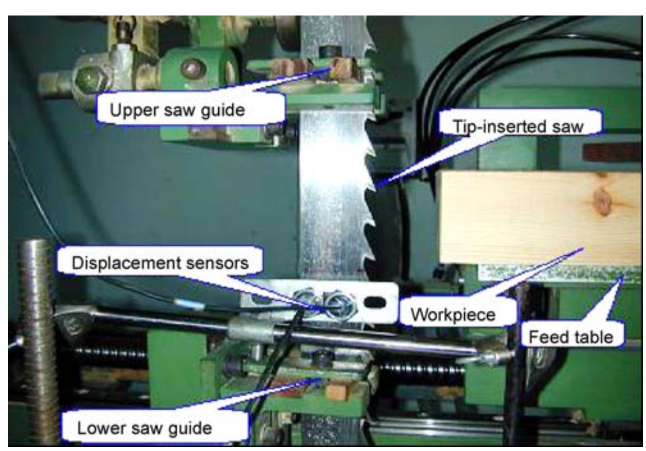


**Fig. 1** Photo of the experimental bandsaw
**Abb. 1** Foto der Versuchsbandsäge

sawing. After sawing, the weight of the sawn board and residual board were determined. The thickness of the sawn board and the residual board at 5 points along the length of the boards were also determined. In order to obtain accurate experimental results, care was taken to ensure that sawdust that adhered to the sawn board was gently removed before weighing the boards. During sawing, the saw blade vibrates and so the measured kerf width on the board $K_i$ is always bigger than the actual saw kerf width $K_b$. Assuming the saw blade does not deviate from an equilibrium position, the measured kerf width $K_i$ under each sawing condition can be calculated from Eq. 1:

$$K_i = \frac{2m_i}{(\rho_i + \rho_{(i+1)}) \times L \times D} \tag{1}$$

where $m_i$ is the mass of sawdust, $D$ is the depth of cut, $L$ is the length of sawn board, $\rho_i$ is the density of the $i$th board, and $\rho_{(i+1)}$ is the density of the $(i+1)$th board. The relative position of the saw kerf width of the saw blade $K_b$, and the measured saw kerf width on the sawn lumber $K_i$ is shown in Fig. 2. The kerf-loss is the difference between $K_i$ and $K_b$, that is, $(K_i - K_b)$.

### 2.3 Measurement of surface roughness

The surface roughness of the sawn boards was measured by using a stylus-type surface measuring apparatus (Taylor-Hobson's Surftronic 3+) equipped with inductive pick-up and a diamond tracer tip. The tracer was moved perpendicularly to the teeth marks. The surface roughness parameter was measured over a traverse length of 25 mm, and cut-off wavelength of 0.8 mm using a Gaussian filter. Gaussian filtering does not simulate a specific electronic filter, but is a mathematical function that is applied to the profile data. A property of a Gaussian filter is the ability to take account of data before and after the effective stylus position. The response at the cut-off value is 50% of the maximum transmission within the band. Traverse speed was set at 1 mm/s. The measured value was expressed as an arithmetical mean deviation of roughness profile over six sampling lengths. Measurement of the surface roughness was determined using the Ra parameter because it is the universally recognized, and most used, international parameter of roughness. The surface roughness of the inner and outer portions of the boards was measured. The inner portion refers to the portion of the sawn board that is within the closed loop of the bandsaw blade whereas the outer portion refers to the portion of the sawn board that is outside the closed loop of the bandsaw. Considering Fig. 2, the inner portion of the board refers to the portion of the board on the right side of the figure, that is, the $i$th board and the outer portion of the board refers to the portion of the board on the left side of the figure, that is the $(i+1)$th board.

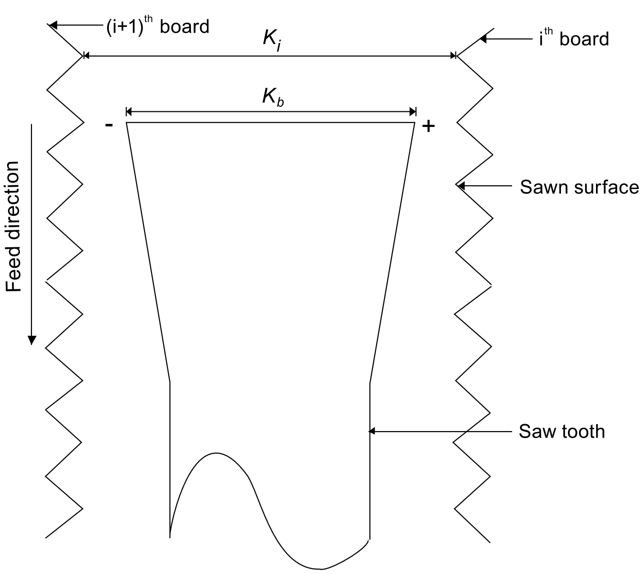


**Fig. 2** Relative position of kerf width of saw blade $K_b$ and the measured kerf width on the sawn board $K_i$. Legend: +: inner portion of the saw within a closed loop of the saw; −: outer portion of the saw within a closed loop of the saw. Note: Motion of the saw tooth is perpendicular to the feed direction

**Abb. 2** Schrankbreite des Sägeblatts $K_b$ und die gemessene Breite der Schnittfuge $K_i$. Anmerkung: Das Sägeblatt schwingt senkrecht zur Vorschubrichtung

### 2.4 Measurement of saw blade vibration and deviation

The Sigview software is a special software developed for signal processing or spectral analysis. By using the Sigview software, the saw blade vibration and deviation were measured. The vibration signals from the two displacement sensors were saved to a computer disk memory using an analog-digital converter. The data was digitized at a sampling rate of 2000 Hz.

## 3 Results and discussion

### 3.1 Feed speed, kerf-loss and saw blade vibration

The relationship between feed speed and kerf-loss under vibration coupling between the feed carriage and the bandsaw frame during sawing with tip-inserted and stellite-tipped bandsaw is shown in Fig. 3. It can be seen that regardless of the type of saw tipping and contrary to expected results, the kerf-loss decreased with increasing feed speed. The results presented in Fig. 3 suggest that there is a vibration coupling between the feed carriage and the bandsaw frame. The results can be explained by considering Sect. 3.2 which describes the influence of bite per tooth on cutting forces.

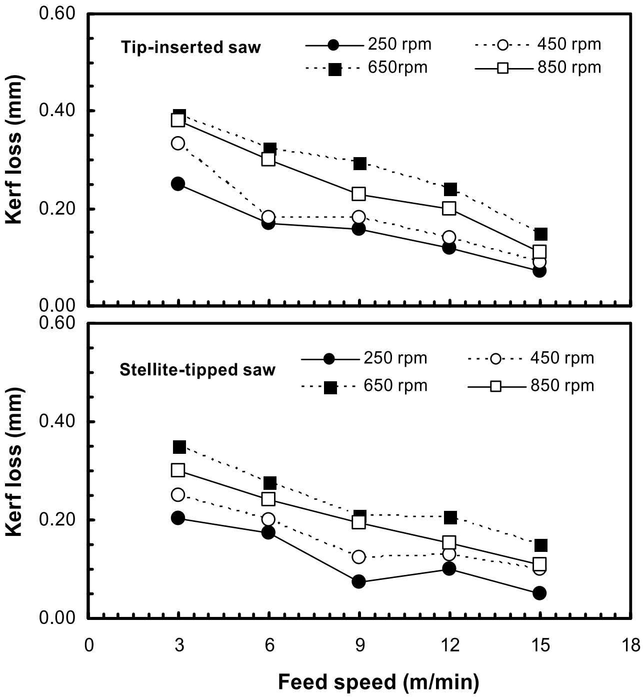


**Fig. 3** Relationship between feed speed and kerf loss of tip-inserted and stellite-tipped saws at varying wheel rotation speed during sawing
**Abb. 3** Zusammenhang zwischen Vorschubgeschwindigkeit und Schnittverlust von Spitzen verstärkten und Hartmetall bestückten Sägeblättern bei unterschiedlichen Umdrehungsgeschwindigkeiten der Bandsägerollen

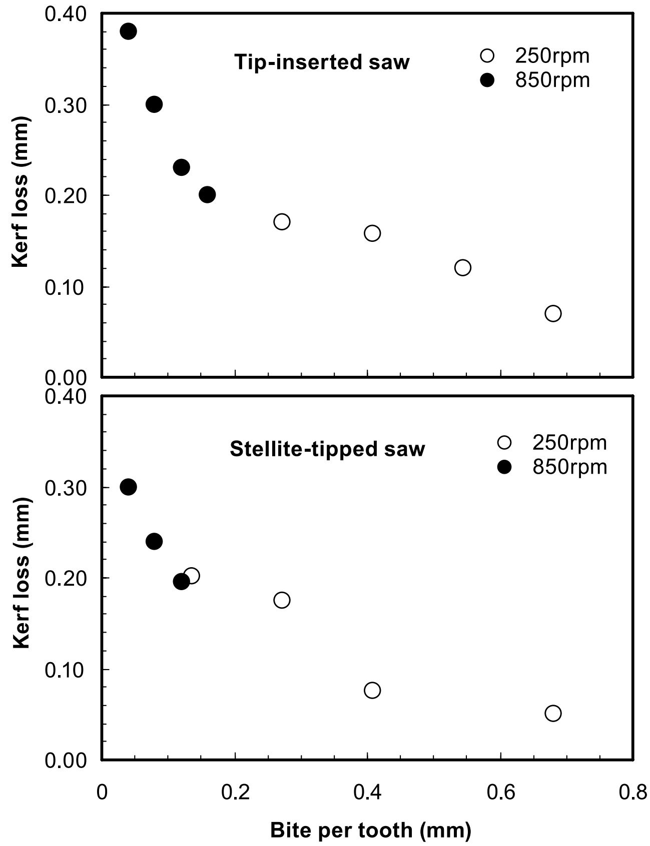


**Fig. 4** Relationship between bite per tooth and kerf loss of tip-inserted and stellite-tipped saws at set up wheel rotation speeds of 250 rpm and 850 rpm during sawing
**Abb. 4** Zusammenhang zwischen Vorschub pro Zahn und Schnittverlust von Spitzen verstärkten und Hartmetall bestückten Sägeblättern bei Umdrehungsgeschwindigkeiten von 250 Upm und 850 Upm

## 3.2 Bite per tooth, cutting resistance and system stiffness

In order to understand the mechanics of vibration coupling between the feed-carriage and the bandsaw frame, the relationship between kerf-loss and bite per tooth of tip-inserted saw and stellite-tipped saw is shown in Fig. 4 to explain why the kerf-loss decreases with increasing feed speed as shown in Fig. 3. Chip formation during sawing was used to explain the phenomenon of decreasing kerf-loss with increasing feed speed or increasing bite per tooth (Fig. 4). The bite per tooth can be calculated from the following equation:

$$B = \frac{pf}{c} \quad (2)$$

where $B$, is the bite per tooth, $p$, tooth pitch, $c$, cutting speed, and $f$, workpiece feed rate. It can be seen from Eq. 2 that as the feed rate increases, the bite per tooth increases. Similarly, when the cutting speed decreases, the bite per tooth increases. For small values of bite per tooth, the cutting resistance has larger value and the lateral cutting forces increase resulting in corresponding increase with amplitude of saw blade vibration. The kerf-loss increases with increasing saw blade vibration. When the bite per tooth is big, the cutting resistance is small resulting in a decrease in saw blade vibration or decrease in kerf-loss.

The relationship between feed speed and amplitude of saw blade vibration during idling or no-load running is shown in Fig. 5. It can be seen that as the feed speed increases, the amplitude of the saw blade vibration decreases. Unlike Fig. 4 where the concept of cutting force and bite per tooth was used to explain the decrease in kerf-loss with increasing feed speed, the concept of system stiffness and its total mass is used to explain the decrease in saw blade amplitude with increasing feed speed during idling. As the carriage feed speed increases, the system stiffness and its total mass also increase resulting in a decrease in amplitude of the saw blade vibration.

## 3.3 Relationship between bite per tooth and saw blade deviation

Figure 6 shows the relationship between bite per tooth, saw blade deviation and amplitude of vibration. It can be seen that as the bite per tooth increases, the amplitude of vibration decreases due to a increase in system stiffness

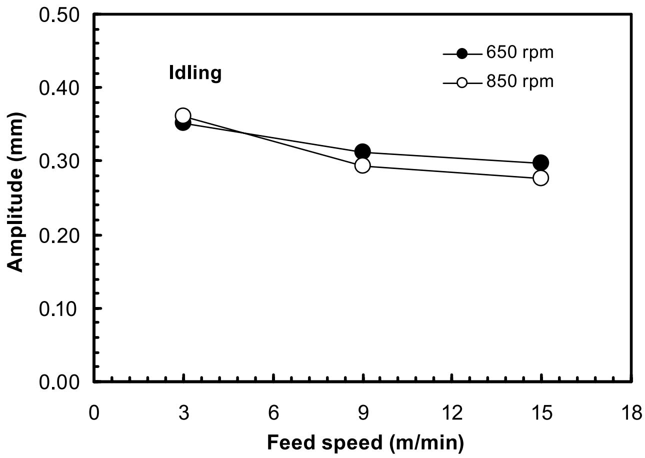


**Fig. 5** Relationship between feed speed and vibration amplitude during idling or no-load running
**Abb. 5** Zusammenhang zwischen Vorschubgeschwindigkeit und Schwingungsamplitude beim Leerlauf

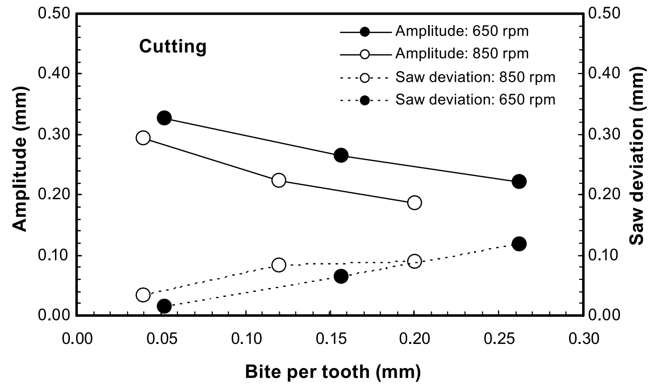


**Fig. 6** Relationships between bite per tooth, vibration amplitude and saw blade deviation during cutting
**Abb. 6** Zusammenhang zwischen Vorschub pro Zahn, Schwingungsamplitude und Sägeblattabweichung beim Einschnitt

and the reduction in cutting resistance. On the other hand, the saw blade deviation increases with increasing bite per tooth.

## 3.4 Surface roughness, wheel rotation speed and feed speed

The relationship between surface roughness and feed speed under set up wheel rotation speed of 650 rpm and 850 rpm during sawing with a tip-inserted saw and stellite-tipped saw is shown in Fig. 7. It can be seen that as the feed speed increases, the surface roughness decreases for the tip-inserted saw. In the case of stellite-tipped saw, the surface roughness appears to be independent of the feed speed. One characteristic feature of the tip-inserted saw is that the surface roughness of boards produced from the inner portion of the saw within a closed loop is much bigger than boards produced from the outer portion of the saw within a closed loop. For visual grading purpose, photos of the surface profile of boards produced from tip-inserted and stellite-tipped saws under set up wheel rotation speed of 650 rpm and 850 rpm,

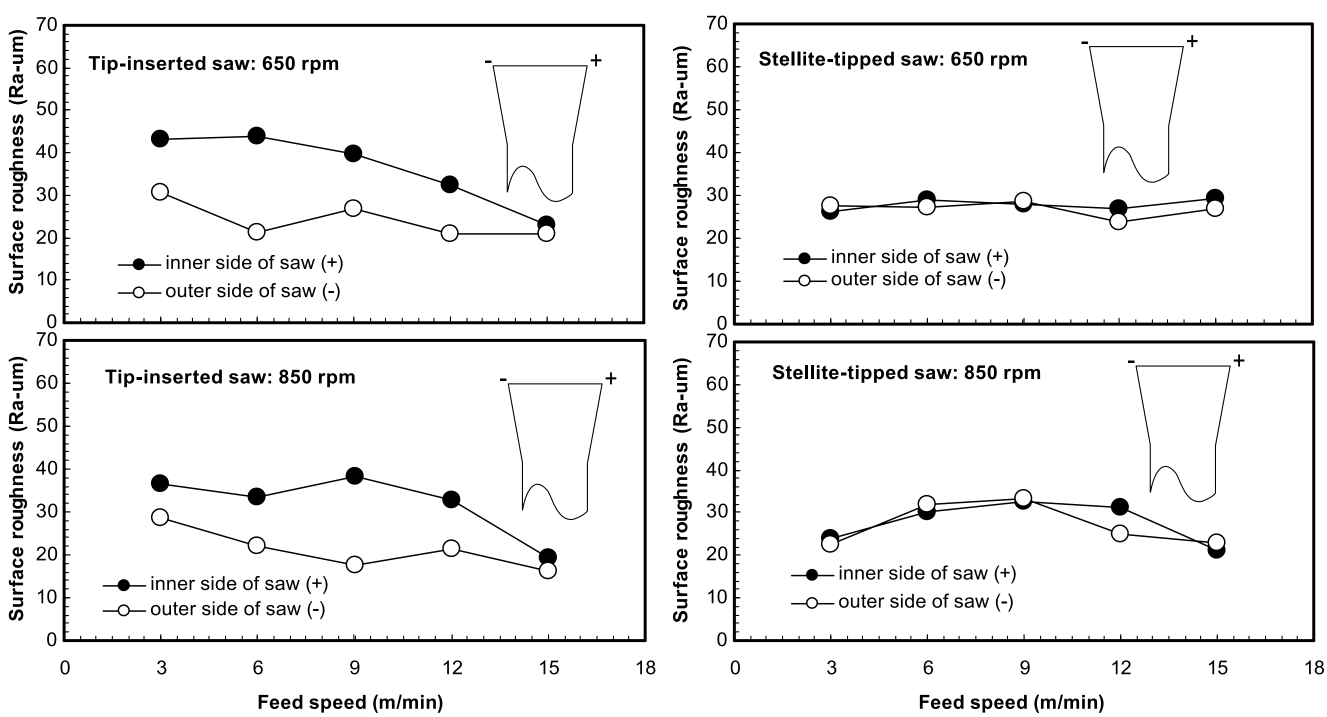


**Fig. 7** Relationship between surface roughness and feed speed
**Abb. 7** Zusammenhang zwischen Oberflächenrauhigkeit und Vorschubgeschwindigkeit

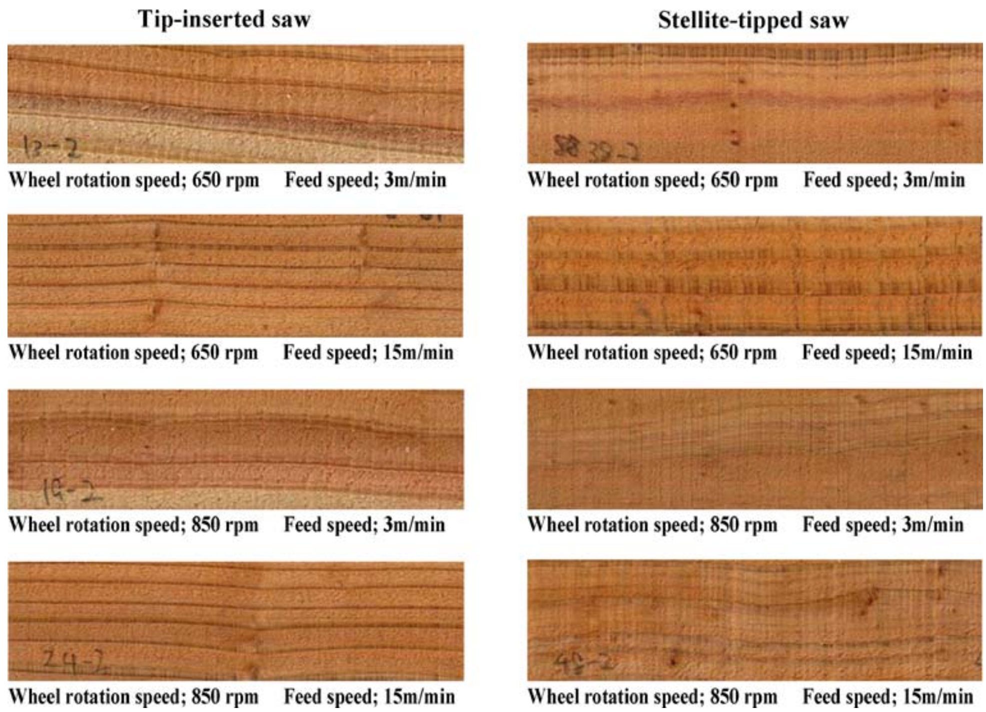


**Fig. 8** Photos of surface profile of boards produced at different feed rates and wheel rotation speeds using tip-inserted and stellite-tipped saws
**Abb. 8** Fotos von Oberflächenprofilen von Brettern, die bei unterschiedlichen Vorschubgeschwindigkeiten und Umdrehungsgeschwindigkeiten der Bandsägerollen mittels Spitzen verstärkten und Hartmetall bestückten Sägeblättern eingeschnitten wurden

and feed speed of 3 mm/min and 15 m/min are presented in Fig. 8. It can be observed that the surface roughness is smoother at high feed rate thus confirming the experimental results of decreasing surface roughness with increasing feed speed.

## 4 Conclusion

The timber industry is compounded with several problems such as poor surface quality, low productivity and low lumber yield. Several attempts have therefore been made by researchers to address these problems. The use of thin-kerf saw blades and automatic control of workpiece feed rate have been introduced as promising techniques for improved lumber conversion.

In this study, a bandsaw machine whose feed-carriage is coupled to the bandsaw frame was used to saw wood samples of Japanese Sugi (*Cryptomeria japonica*) into boards. It was observed that as the workpiece feed rate or bite per tooth increased, the saw blade vibration decreased and the volume of sawdust produced also decreased contrary to expected results. Furthermore, it was observed that as the workpiece feed rate increased the surface roughness decreased contrary to expected results. Analysis of the experimental results clearly indicates that the increase in kerf-loss with decreasing bite per tooth is due to an increase in cutting resistance. Furthermore, there is an increase in the system stiffness when the carriage feed speed increases thus accounting for the reduction in the amplitude of the saw blade vibration with increasing feed speed during idling or no-load running The research findings clearly suggest that a bandsaw machine whose frame is coupled to the feed-carriage is a promising technique for increasing lumber recovery and improving upon surface quality.

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